U.S. Department of Agriculture Agricultural Research Service July 1991

Agricultural Research

Rhapsody In Green
Collecting the Earth's Diversity
Story on Page 4

CALVIN SPERLING

USDA Plant Hunters

Bring 'Em Back Alive and Growing

With the threat of extinction adding urgency to their efforts, ARS plant collectors gather snippets of the Earth's botanic diversity.

In this Colombian market are displayed white carrots, dark red sweet potatoes that are native to the Andes and now grown worldwide, and pink ullaco, a traditional Andean potato not currently grown in the United States.

Somewhere up a tributary of the Amazon River on a 30-by 12-foot barge with 14 people aboard, 1947:

About 5 AM there was jolt and a loud crashing and splitting of wood. The barge has run into a leaning tree along the river's edge and the already badly damaged cabin was smashed. With my flashlight, I saw that the tree was in young fruit, with a recently fertilized ovary that is, so I broke off a few branches....When dawn came, I examined the plant—it was Micranda minor which I was especially anxious to collect!

—From the journal of USDA plant explorer Richard Schultes.

During World War II, USDA sent botanist Richard Schultes exploring through South America in search of rubber trees that could be the basis for a New World rubber industry.

The attack on Pearl Harbor and the Philippines had sealed off the United States' access to the rubber plantations of the Pacific. Rubber would be particularly needed for airplane tires during the war; the synthetic rubber tires of the day could not handle the weight of a landing airplane.

"The reason there were no rubber plantations in the New World was the presence of a leaf disease," Schultes explains in a much more recent recounting of his plant explorations. "All commercial rubber plantations depend on one species of rubber tree, and there are nine others. One of them may have some resistance to the disease."

Seven of the nine species were collected for study, thanks to Schultes.

Schultes is one of many scientists that USDA has sent exploring through the years to enrich the variety of crops grown in this country. The plants that USDA explorers have collected have literally changed the face of agriculture and gardening worldwide.

CALVIN SPERLING

On the slopes of the Cayambe volcano in Ecuador, Head of Plant Exploration Office Calvin Sperling seeks wild relatives of the carrot.

Other countries have benefited as much as the United States. Plant exploration often develops into cooperation and exchange of plant germplasm between scientists and countries. ARS always shares its discoveries with host countries, each year sending abroad far more plant germplasm than it collects.

As a prominent plant explorer for USDA from 1941 to 1954, Schultes not only collected rubber plants and their relatives but he also brought back medicinal plants used by natives of the Amazon region to treat illnesses.

"There are over 1,600 species of plants used for medicinal purposes alone by people in the Colombian Amazon and only a few of them have ever been looked at by scientists," says Schultes. "Yet there is the destruction of millions and millions of acres each year, and plants are being lost. We need to learn what plants are out there and what they can do for us in agriculture and medicine."

During his career, which is far from over at age 78, Schultes has brought back nearly 24,000 plant specimens, 300 of them previously unknown to science.

He helped collect curare vines that provide the muscle relaxant now usually given patients before surgery.

Another example: he more recently collected a tree in the Colombian Amazon basin, called ucu uba, in the nutmeg family. Preliminary testing indicates that a resin from its bark may be a highly desired suppressant or even cure for skin fungal infection.

Discoveries Have Far Reaching Impact

- The rootstock on which many U.S. peaches are grown, originally collected in China in 1898.
- The naval oranges that created a California industry brought back from Brazil.
- The Durum wheats Kubanka and Arnautka that set the standard for the Northern Plains for decades, collected in southern Russia in 1900 by USDA researcher Mark A. Carleton .
- A peanut discovered in Peru that had the genes for resistance to two major diseases of that crop, collected in 1966.
- A wild oat that has resulted in one of the most disease-resistant oat varieties ever developed, found in Israel in the 1960's.

This sampling doesn't even scratch the surface of genetic treasures that USDA plant explorers have collected and shared with other nations through the years.

"Genetic diversity is the key to maintaining and improving agriculture, whether it's discovering new crops or finding the genes for resistance to diseases and insects, drought tolerance, better flavors, durability, or some other needed traits to be added to crops already being grown. What plant

explorers do is find and bring back that diversity," says Calvin Sperling, the current head of ARS' Plant Exploration Office.

The reservoir of genetic diversity that collecting has built has sometimes played a direct role in keeping crops safe from large-scale destruction.

"Many of the crops we take for granted in this country originated in other places, and their genetic base here is very narrow," Sperling explains. "The situation is similar in many countries."

A narrow genetic base means all varieties grown are closely related and may share disease and insect susceptibility, so a single disease could wipe out a crop.

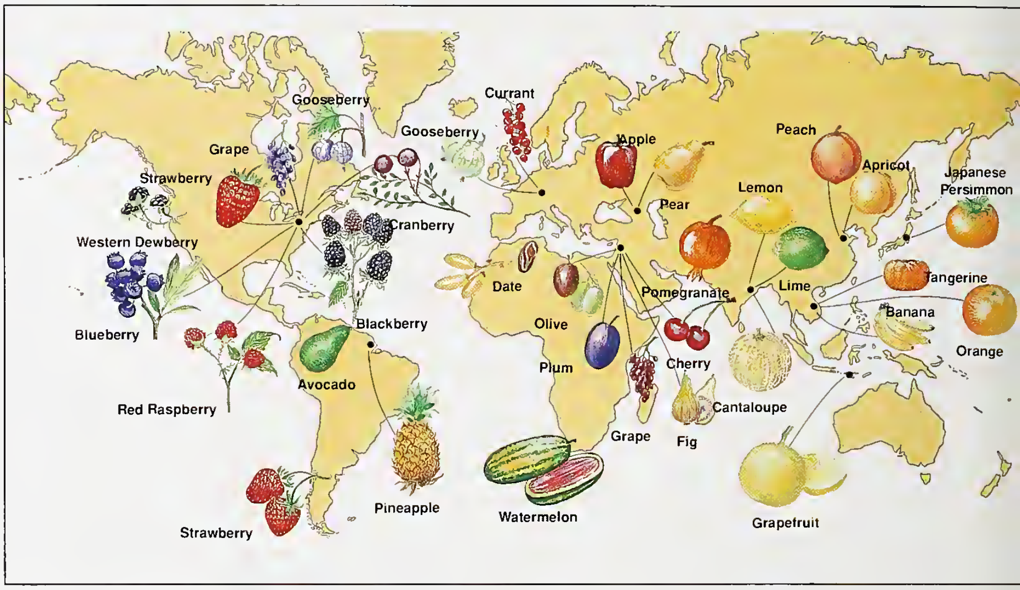
In 1970, southern corn leaf blight, which had up till then been a minor disease, suddenly became virulent, destroying almost $1 billion worth of corn and reducing yields by as much as 50 percent. A single gene, T*cms*, was responsible for corn's susceptibility to the new type of leaf blight and, back then, over 80 percent of the corn being grown in the United States carried the gene.

A crash breeding program shifting production to nonsusceptible strains succeeded in averting a major crisis.

When wilt and blight threatened to kill off the Virginia spinach industry in 1920, the genes for resistance to the diseases were found in a spinach that came from Manchuria around 1900.

Genes from the Manchurian spinach have spread far beyond the Virginia Savoy cultivar developed to meet that original disease outbreak. Today, the genes are present in almost every multi-disease-resistant spinach grown.

"Plant exploration has also provided new crop industries for the United States," Sperling says. A USDA plant explorer located germplasm which was the starting point for California's avocado industry during a collecting trip to Mexico, for example. Dates, sorghum, a variety of forage grasses, and tung oil were all new crops introduced through USDA exploration.



Centers of origin for some fruits.

As ARS' chief plant explorer today, Sperling coordinates about 10 trips a year, with a budget of about $207,000 for the 1991 fiscal year. He goes on two or three of them each year himself; the rest are conducted by other ARS scientists or cooperating researchers.

JAMES BALLINGTON


Wild blueberry found in Ecuador by James Ballington of North Carolina State University.

When trips can take a plant explorer on horseback to 13,000 feet in the Andes, images of bold exploits come to mind.

But Sperling strongly demurs. "Plant explorers are just scientists, not adventurers. They go where the plants are—in that case, it was for the wild relatives of potatoes," he says.

Quick, Before It Disappears!

The need for plant collecting has become more urgent as plants are lost to the encroachment of modern civilization—either through the destruction of habitat or as traditional varieties grown by remote peoples are replaced by commercial varieties, Sperling points out. "We don't know what genes those traditional varieties may have," he says.

In southeast Turkey, Sperling collected "one of the scraggliest wheats I'd ever seen cultivated." But bread made from the wheat was "the best bread I've ever had."

But who knows how long it might be before farmers in that region replace it with a modern high-yielding wheat?

ARS plant geneticist Devon L. Doney might bring Indiana Jones to mind with his occasional exploits like rappelling down rocky cliffs to inaccessible beaches in Ireland and Wales after the wild relatives of sugar beets, in a race against time before their habitat disappears.

Sea beets grow only on rocky beaches near or in the saltwater near the high-tide line—wild habitats that are being lost in many areas to tourism and development. "Cement sea walls, constructed along Great Britain's Atlantic seacoast to protect and maintain the coast, are destroying the natural habitat of wild sea beets," Doney says. "We need to know what's there before it disappears forever."

One of the wild sea beets collected may hold the genes for resistance to diseases like leaf spot, a major problem for sugar beet growers in the Northern Plains, Doney hopes. The crop's current resistance to leaf spot can be traced to introductions from an Italian scientist, who developed leaf-spot-resistant varieties 60 years ago by crosses with wild sea beets. A change in the disease could find all of the sugar beets in the United States vulnerable.

Sea beets may also have genes that breeders could use to give sugar beets more frost and drought tolerance and most especially salt tolerance, Doney explains, "given where they grow."

Collecting plants not only provides breeders with a larger pool of sources, but also helps taxonomists get a better picture of how plant families are organized.

ARS botanist David Spooner found what appears to be a natural hybrid of two very different wild potatoes on one of his regular exploring and collecting trips to Latin America. Not only does Spooner spend 2 to 3 months each year in Latin America collecting potatoes, as part of his joint appointment between ARS and the University of Wisconsin Horticulture Department, but he also conducts research on taxonomic and evolutionary relationships in potatoes.

Spooner is using DNA analysis on the putative hybrid, and on other potatoes he has found, to uncover new taxonomic relationships between species. He often brings researchers back to this country from

Wild sea beets, which tend to grow on inaccessible beach cliffs, may hold the genes to improve U.S. sugar beets. ARS scientist Devon Doney and plant pathologist E.D. Whitney (now retired) are collecting specimens on the coast of southern Ireland.

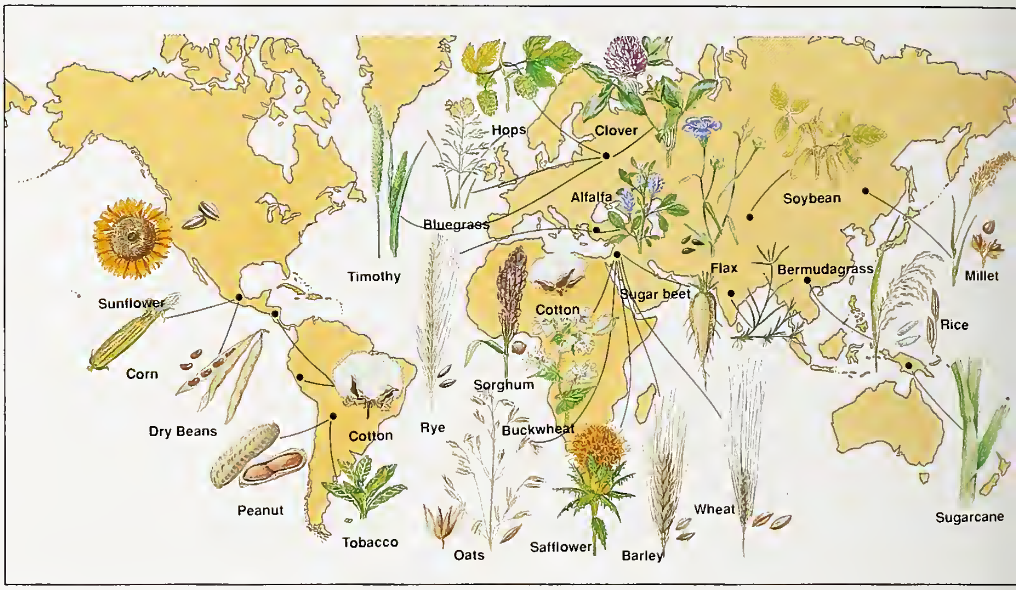
the countries he has collected in to conduct follow-up evolutionary studies. The foreign researchers share authorship on scientific papers as well as the germplasm collected.

Where To Go

One strategy that has historically been used in selecting sites to explore is to look along the same latitude.

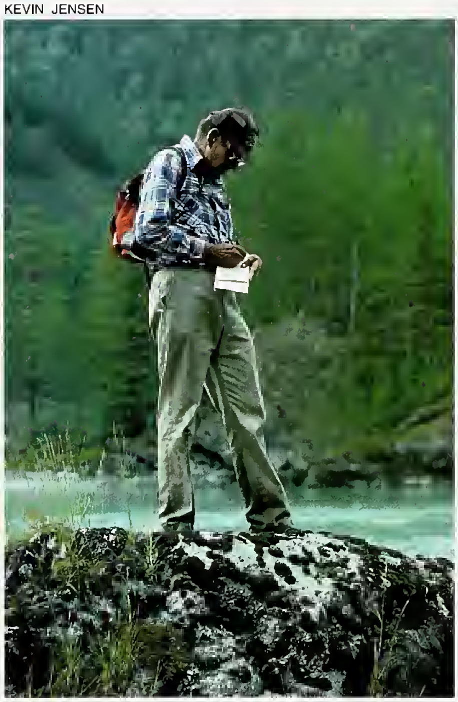
John Ellis, a contemporary of Benjamin Franklin, pointed out in 1770 that "Philadelphia lies on the 40th degree of north latitude, the very same as Pekin in China, and nearly the same with Madrid in Spain and part of California," and that these were therefore logical places to search for plants.

Other strategies call for looking at the centers of origin—where plants originally evolved. "That's where you are likely to find some of the greatest diversity—or in the part of the world where a crop was first domesticated," Sperling explains.



Centers of origin for some grain and oilseed crops.

KEVIN JENSEN



Now retired, ARS geneticist Douglas R. Dewey collects wheatgrasses and wild rye grasses in the Altai region of the Soviet Union. Dewey's plant collecting and research have helped make major improvements in forages in the United States.

Spooner adds, "In planning an expedition, our first priority is to collect species that have no living representatives in our germplasm system. We expand our collections in as many geographical areas and ecological sites as possible in an attempt to capture diversity."

Wild potatoes are found from southern Chile to Nebraska, and a single variety may appear in many places in this range. A specimen from the highest elevation a variety exists at or one growing as a epiphyte on a tree when others of that type don't grow in that fashion may have traits not in the main genetic pool for a species. Spooner has found examples of both in his potato exploring and collecting trips to Latin America.

To date, Spooner and his international collaborators have collected over 300 wild relatives of potatoes from Mexico, Ecuador, Argentina, and Chile.

Locating plants in cultivated fields and in existing germplasm collections of other countries can be as rewarding as searching the wilds.

Sperling, ARS horticulturist David W. Ramming, and Maxine Thompson, a veteran plant explorer from Oregon State University, recently spent 3 weeks in the Soviet Union where they looked for apricots, mostly in orchards and botanic gardens. Some of their finds already appear to hold great potential.

Apricots came from central Asia, at least as the site of secondary origin—they may have first evolved farther east in China, Ramming says.

From the northern edge of the apricot's range, they collected one that appears to be frost-hardy. "In an area that has spring frosts, this apricot seemed to be doing very well," Ramming says. "That's a trait we'd like to have."

The group also found an apricot that had very high soluble solids, a trait important in making dried fruit and in flavor. "It had over 20 percent soluble solids, when we have considered 13 percent high before," Ramming says.

Another one produces sugar much earlier in the fruit's growth, which would make it possible to ship apricots earlier in the season while the fruit is still firm, again a most marketable trait.

Most exciting of their finds was a smooth-skinned apricot in Kazakhstan in the southern Soviet Union. "If the smooth-skinned trait can be incorporated here, it will significantly expand the apricot industry," Ramming says.

Commercial development of such an apricot is at least 15 to 20 years away. Before any such breeding project can begin, the samples that Ramming and Sperling brought back have to go through quarantine to ensure the samples do not introduce any foreign diseases into the United States, a process that can take up to 5 years.

The serendipity that helped Schultes find his elusive wild rubber relative continues to assist USDA plant hunters.

While Sperling and Thompson were examining an apricot orchard in Uzbekistan, they found a walnut tree that bore 50 percent more nuts per cluster than is typical. Ramming came across a mulberry that was so sweet "it tasted like someone had poured sugar over it." Unfortunately, the sample Ramming had collected died in quarantine. He hopes another one can be gained from the Soviets.

Even Before USDA

Plant exploration and collecting to benefit agriculture has a long history in the United States.

President John Quincy Adams sent a circular to all American consuls in foreign countries in 1827, directing them to send seeds and cuttings back home. The circular came complete with five pages of directions on packing and shipping plant materials, including protecting them from salt spray "especially when the waves have white, frothy curls upon them."

The first direct government funding for plant exploration came in 1839, 23 years before the Department of Agriculture was created. A $1,000 appropriation was channeled through the Patent Office, which had charge of agricultural matters at the time for the collecting of tea seeds.

When the federal Department of Agriculture was formed in 1862, the act creating it specifically required the department *to procure, propagate, and distribute new and useful varieties.*

The Grand Age of Exploration

The grand age of plant exploration began under the tenure of Secretary of Agriculture James Wilson in 1897. Wilson appointed David Fairchild to head a new USDA unit called the Section of Seed and Plant Introduction and gave him a budget of $20,000. Fairchild was to serve in this capacity for 27 years, creating the first truly organized system for the introduction of new crops and keeping records on their progress.

Fairchild hired Frank Meyer as chief plant explorer. Together they have come to be regarded as the founding fathers of USDA plant collecting.

Although his name is not widely known, Meyer brought back an amazing variety of crops to the United States from barleys and chestnuts to the first ever introduction of zoysia grass.

It is hard to track the effect of some of Meyer's finds. Once he collected a plant, it entered breeding programs and germplasm repositories. By the time it emerged, decades later, as an important economic crop, his name was seldom still associated with it.

He was a pioneer in soybeans. Before Meyer went to China in 1905, only eight varieties of soybean were grown here, mainly as a forage crop. Between 1905 and 1908, Meyer added 42 new soybeans, which have given rise to thousands of varieties over the years.

Among those soybeans he collected was the first oil-bearing soybean, the basis of an industry worth billions of dollars today.

Guidelines for Plant Hunters

For modern plant hunters, collecting germplasm has become an activity of international cooperation. Today, collecting trips are arranged as collaborations between U.S. and host country scientists.

To ensure the maximum benefit for both the United States and foreign germplasm systems and to prevent any harm to the environment, ARS recently created guidelines for conduct and ethics during plant exploration trips.

The need to share all collected material is a major consideration in the guidelines. All collected germplasm and herbarium specimens are divided at least equally with the host country.

"And if a sample containing no more than three seeds were collected, two of them would go to the host institution and one to us," explains Calvin Sperling, head of ARS's Plant Exploration Office who drafted the guidelines. "An even better arrangement would be for the host country to grow out all three and later supply a small sample to us."

It is also important for a host country to understand before an expedition that all germplasm collected with the support of USDA is deposited in the National Plant Germplasm System (NPGS) and is freely available to all valid users, domestic or foreign. "Some countries have restrictions on the distribution of particular genetic resources," Sperling says. "While we respect their right to do that, the NPGS will not restrict access to any material in our system."

The U.S. NPGS sends out much more each year than it receives through collecting.

The guidelines also require that all plant collecting "be done with a conservation ethic in mind." Collecting must not endanger natural plant populations, and enough must always be left behind so that the plant population can regenerate naturally.—By **J. Kim Kaplan,** ARS.

One contribution of his did not quite take. Meyer was ahead of his time in the early 1900's when he strongly advocated that the United States pick up on an Asian soybean industry and begin producing a food called tofu.

It took almost three-quarters of a century after Meyer brought the crops back from his Asian expeditions before American markets saw the worth of bean sprouts, Chinese celery-cabbage, and alfalfa sprouts.

The Meyer lemon is an important source of frozen lemon juice in Florida and is grown commercially in Texas, South Africa, and New Zealand. The northern wild peach he brought back energized the peach industry when it gave rise to a nematode-resistant rootstock released in 1961. That rootstock has also allowed apricots and plums to be grown in dry, alkaline soil, expanding those industries.

And of course there was the spinach Meyer brought back from Manchuria that saved the Virginia spinach industry.

Landscape plants and ornamentals have also benefited from Meyer's collecting. His introductions are a source of genes in the hardy yellow roses that grow in New England.

Landscape trees, from the Amur cherry to the dwarf lilac and the Bradford pear, were developed from his gatherings. He was the first plant hunter in modern times to find the maidenhair tree—the ginkgo—in the temple gardens of China.

Most widely used of all the drought-resistant trees Meyer brought back were the Siberian and Chinese elms. When the drought of the 1930's threatened to turn the prairie states to dust, Meyer's elms formed a large part of the 17,000-mile shelterbelt that was created. This tree-lined windbreak planted between 1935 and 1942 helped reduce wind erosion and conserve soil for millions of acres.

CALVIN SPERLING

ARS scientists Walt Kaiser (left) and Fred Muehlbauer look for wild lentils at the edge of a wheatfield in southeastern Turkey. The seeds are very small and fall to the ground as soon as they mature; they are collected by sieving the soil around the plants.

Once Meyer's collected plants were brought to the United States, many of them were grown on a farm set aside for such cultivation. The 400 acres used for this purposes were known as the Arlington Farm. Today, instead of being home to such exotic crops as date palms and sugarcane, the acres are the south parking lot of the Pentagon.

Meyer helped open up the field of plant exploration in Asia. Few Western plant hunters had ever penetrated the outlying districts that he combed for plants. Not only the plants that he collected but also the techniques he developed for cataloging and shipping have had a lasting effect, literally changing the face of agriculture and landscaping in the United States and many other countries.

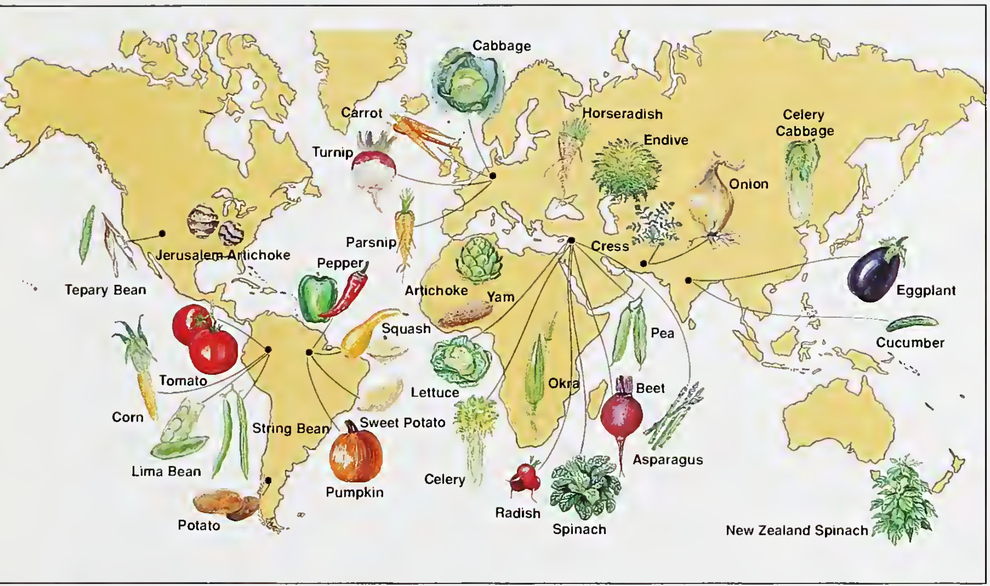
The Second Grand Age

In 1946, a new mandate was handed down by Congress for USDA to collect and maintain genetic diversity. Richard Schultes was among several USDA plant collectors who made the 1940's and 1950's a second grand age of plant exploration.

Howard Scott Gentry, one of the country's most respected plant explorers, worked for USDA for 24 years until he retired in 1971.

His contributions have had wide spread impact. Some of the wild beans he collected in Mexico and Central America have natural resistance to bean weevils and other insects. Others have shown a natural resistance to city smog.

He was involved also in USDA's search for plants that could serve as sources of steroids in the 1950's. He logged thousands of miles across the southwestern United States, Africa, and Asia exploring and collecting plants that might provide the raw materials for medicinal steroids. That program eventually analyzed about 7,000 plants. Wild yams that Gentry collected were found to be some of the best sources.



Centers of origin for some vegetables.

He is considered by many to be one of the country's top field botanists. Botanical expertise such as his is essential to plant collecting. Many yam species resemble each other on first sight. But only about a dozen of the more than 60 species of yams were significant steroid sources. Gentry could bring back what he was looking for.

"There is an unending need for new germplasm," he observes. "As new pests and new diseases develop, resistance to them will be needed. The germplasm that contains these resistances must be where the breeders and the geneticist can get at it."

Jack R. Harlan, who explored for plants for USDA in the forties and fifties, is best known for the powerful impact his wheat collecting has had.

Foremost of his introductions is a wheat known simply as PI178383 that Harlan and Turkish colleague Osman Tosun collected in 1948 from a field in Fakiyan Semdinli, Turkey.

The wheat looked terrible—it lodged, had no winter hardiness, and was susceptible to leaf rust. "It was a hopelessly useless wheat but was dutifully conserved," Harlan wrote of PI178383.

But 15 years later when stripe rust suddenly began making major incursions in the Pacific Northwest wheat crop, PI178383 was found to have resistance to 4 races of stripe rust, 35 races of common bunt, and 10 races of dwarf bunt. It also had tolerance to flag smut and snow mold.

T. R. DUDLEY

Wild viburnum from Anhui Province of China.

Today, PI178383 appears in the ancestry of virtually all of the wheats grown in the Pacific Northwest.

Oddly enough, it may turn out that PI178383 did not originate in southeastern Turkey. In 1986, Sperling went back to Fakiyan Semdinli to collect more of PI178383 and other possibly disease-resistant wheats of the area.

He discovered in conversations with the region's farmers that they were relatively recent immigrants, having moved there only in their grandfathers' time.

"The farmers came to Turkey from northern Iraq and brought their wheat along with them," Sperling says. "PI178383 and any other related varieties originated in northern Iraq."

Sperling had hoped to plan a collecting trip to northern Iraq, "but a war seems to have gotten in the way."

Unhappily, the area Sperling believes the farmers came from is within the area that has been the scene of major upheaval in the last few years, and "no one knows if the traditional varieties have survived."

Preservation in Place

A new idea for preserving wild relatives has begun to gain popularity, according to Sperling.

"We may not need to put all the wild relatives of a crop into a gene bank," he explains. "It may be more practical to preserve the plants in situ—on site in their native habitat as part of an ecological reserve."

Instead of collecting the diversity of wild species in a region and bringing it back, the wild species in that area are inventoried and left in place. Naturally, the idea only works if the inventoried area is kept undisturbed or managed as a reserve and someone is monitoring it, Sperling adds.

Of course, small samples of some of the diversity will need to be stored in a gene bank, where it will be accessible to scientists. If something promising is

found, scientists can hopefully collect additional samples from the reserve.

Sperling, along with Raul Castillo of the Ecuadorian Department of Resources, ARS botanist Jim Duke, and Shirley Keel from the Nature Conservancy, recently set up two test sites for in situ preservation in the Ecuadorian highlands.

They made a quick inventory of the wild relatives of agricultural crops present in two Ecuadorian reserves, one in the south and one in the north.

The group found wild relatives of potatoes, blueberries, currants, gooseberries, blackberries, beans and even papayas. Wild tomatoes and walnuts were found nearby. Only a few herbarium specimens were taken; the rest were simply cataloged.

"In some cases, it may be more cost-effective to re-collect what a researcher needs each time from the wild, once we know where it is, than to maintain the total diversity of wild relatives in a gene bank," Sperling says. "Gene banking is costly and requires long-term commitment to preserve seed from what is collected and then grow it out periodically to maintain viable seed supplies."

A side benefit of preserving plants in place is the additional justification for conservation efforts.

"Conservationists have rarely taken into account the potential value that wild relatives of crops may represent when creating a case for preserving an area," he says.

At least 29 of the 189 plant taxa now listed as endangered or threatened by the U.S. Fish and Wildlife Service may have some present or future potential as genetic resources of agronomic or horticultural crops.

While the plant exploration and collecting system does not function as a conservation agency, exploration and preservation do share common goals and the two can go hand in hand.

But in-place preservation will never be able to do the whole job. "It can only be a complement to collecting germplasm and off-site preservation," Sperling says.

Closing the Gaps

Sperling is currently hard at work on a project that keeps him at his desk at the Beltsville, Maryland, Agricultural Research Center. He is trying to assign priorities as to which collecting trips are most needed.

"We need to systematically fill in the gaps in various collections and crops," Sperling says. "So the first need is to determine where the gaps are."

In the past, collections have primarily resulted from scientists who

David Fairchild, on exploration trip to Ceylon in February 1926, with an example of a King coconut. Fairchild is considered a father of modern plant collecting in USDA.

arranged to get or collect some material they were interested in working with. The materials would then be passed on to the germplasm system.

For instance, all of the cranberry cultivars grown today come from germplasm originally collected from just two areas in the United States. Who knows what additional useful traits may be available in other areas," Sperling says. "Or wheat—we may have over a thousand samples of wild relatives, but they come from a relatively few areas. Many unexplored areas still exist in the Soviet Union, China, the western Mediterranean, and even North Africa."

To help set objectives, Sperling has prioritized planned acquisitions into four groups: land races of plants cultivated in the world's remaining remote areas, wild progenitors of domesticated plants throughout their geographical range, plants exhibiting unique chemical or biologically active properties, and plants of evolutionary rarity—including the evolutionary "dead end" taxonomic groups, and unique plant families that may contain novel genes not found elsewhere in the plant kingdom.

"By collecting from these groups, combined with in situ preservations, we may one day have a better knowledge of what plants have to offer," Sperling says.

Although Meyer probably did not use such terms as germplasm, gene pool, and in situ preservation, he certainly understood the need for continually improving the diversity of U.S. agriculture, for in 1908, he wrote:

"In the future we will create unheard-of strains of fruits and shrubs and trees and flowering plants. All we need now is to build up collections so as to have the material at hand....We are only cutting out a few steps in the mountain of knowledge and others have to mount by our steps."—By **J. Kim Kaplan,** ARS.

For addresses or phone numbers of ARS scientists mentioned in this article, contact the Editor, Agricultural Research, Room 316, Bldg. 005, BARC-West, 10300 Baltimore Blvd., Beltsville, MD 20705-2350. Phone (301) 344-3280. ◆

Changing the Landscape

Seeking the germplasm that can lead to trees tough enough to stand up to city smog, shrubs to thrive in New England winters or southwestern summers, and plants to beautify the country's woody landscape are all the business of ARS' U.S. National Arboretum.

The arboretum has been a modern-day leader in collecting and conserving the germplasm of landscape plants. From the arboretum's work has come such advances as crepe myrtles in a whole forest of colors. The gene pool for viburnum was widened significantly by the discovery in 1985 of a rare wild viburnum from the outermost Korean island in the Yellow Sea, with the potential to be an entirely new landscape plant for the United States.

Much of the arboretum's collecting has centered in Asia because of the diversity of its plants. "China is a fifth of Asia, and it alone has climates from tropical to alpine. It has at least two times as much genetic diversity as North America, particularly in the temperate region," explains ARS botanist Theodore R. Dudley. "The irregular and random activity of glaciers in the Pleistocene created isolated refuges between the tongues of ice masses."

In 1980, Dudley was part of the first Sino-American plant exploration of the People's Republic of China. Not only did the trip collect more than 650 germplasm samples, but it has given rise to a spirit of cooperation and plant exchange between the two countries.

One of the exciting finds Dudley made on that trip was an evergreen flowering dogwood—the first of its type to be brought back as living germplasm.

"Its leaves turn the color of port wine in the fall and stay that way all winter, and then it flowers in May," Dudley says.

In 1987, Dudley became the first foreigner invited to visit the Zhejiang Province Nature Reserve in the remote mountains of western China. He helped make recommendations for the preservation of the many rare, endangered and threatened plants there.

In a wet mountain valley, he discovered a living specimen of one of the rarest firs in China, *Abies baishanzuensis,* of which only three trees are known to still stand in the wild.

THEODORE DUDLEY

A superior wild crabapple from Hubei Province of China.

Not all of Dudley's trips are to places as remote as the wilds of China. In 1969, on an exploring trip to West Virginia, Dudley found a very rare deciduous holly that is just now coming into the nurseries. "This is a very hardy shrub with large red fruit and it should be quite significant as a landscape plant," Dudley says.

The arboretum's push for plant collecting hit its stride with John L. Creech, who became director in 1973.

Creech, who joined the ARS Office of Plant Exploration in 1947, began collecting landscape plants exclusively in 1956 when USDA reached an agreement with Longwood Gardens, of Kennet Square, Pennsylvania, which provided some funding for trips.

Among the many specimens Creech collected was the crepe myrtle, which has given rise to mildew-resistant trees with lovely cinnamon colored bark. He also brought back rhododendrons that have significantly broadened that plant's diversity.

Creech retired in 1980 but exploration and collecting have continued under the arboretum's current director H. Marc Cathey. There have been collecting trips to Japan and Korea and a second one to China. Several of these trips have been funded by the Friends of the National Arboretum.

On a 1984 trip to the northwest coast and islands of Korea, arboretum chief horticulturalist Sylvester G. March and Barry Yinger, a former curator of Asian collections at the arboretum, collected more than 500 germplasm specimens, many of them surviving in highly stressful conditions.

Camellias were collected from the northern tip of their natural range, and a viburnum was found thriving despite regular exposure to salt spray.

The following year, Dudley and Yinger explored the coastal areas and islands of southwestern Korea. Over 600 more accessions came back from that trip, including many drought and salt-tolerant hollies and Korean dogwoods. One of the hollies was a naturally occurring hybrid that combined the best ornamental qualities of the Chinese holly and the entire-leafed holly.

It takes years before the impact of germplasm collected on an exploration trip begins to show up in commercial nurseries. But in the words of Thomas Jefferson, whom Creech often cites: "The greatest service which can be rendered any country is to add a useful plant to its culture."—By **J. Kim Kaplan,** ARS.

SCOTT BAUER

Soybeans being checked by plant pathologist Vernon Damsteegt are infected with soybean dwarf virus. (K-4094-7)

Spying on an Elusive Virus

When is a deadly disease not a deadly plant disease? And why do only some aphids carry it?

It's a very confusing virus: It needs a very specific insect to transmit it. Or does it? It causes a plethora of symptoms in different hosts—even no symptoms in some. And it's an exotic organism. Or is it?

To further muddle matters, the virus has had two names. Researchers in Japan refer to the virus as soybean dwarf virus (SDV) because it attacks soybeans. Investigators in Australia, New Zealand, and Tasmania have called it subterranean clover red leaf virus because it attacks clover.

But are they really strains of the same virus? And if so, could they start attacking soybeans or other crops in this country?

These questions are important to the safety of crops in this country. Agricultural Research Service plant pathologists Vernon D. Damsteegt and Oney P. Smith and biological lab technician Andrew L. Stone are tracking down some of the answers at the Foreign Disease-Weed Science Research Unit in Frederick, Maryland.

It's known that the virus is transmitted from plant to plant only by aphids—somewhat as yellow fever virus is transmitted person to person only by mosquitoes. Similarly, only the female aphid carries the virus as with virus-transmitting mosquitoes.

The aphid, a little soft-bodied sapsucker, sticks its mouthparts into leaves or stems, puncturing them and

probing to find just the right spot to feed. Sucking away steadily, the aphid must feed on an infected plant for at least half an hour for the virus to move from the plant into the aphid's gut, into its blood system, and then to its salivary glands.

When the aphid feeds again, the virus picked up from the first plant is neatly deposited into the phloem of the second plant and subsequently spreads throughout the plant, infecting it. The virus must rely on the aphids to find just the right host where it can thrive.

In Japan, the virus relies on the foxglove aphid, *Aulacorthum solani*, to find soybean host plants. In the United States, however, the virus has not been found in soybeans. Foxglove aphids here shun soybeans. The reason for this apparent aversion remains a mystery to entomologists.

Besides having a specific aphid carrying it to specific plant species, the soybean dwarf virus in Japan consists of two strains, each producing dramatically different disease symptoms.

The SDV-Y (yellowing) strain causes the older leaves of an infected plant to turn a brilliant yellow color and the leaves to appear sparse. But when the SDV-D (dwarfing) strain attacks, the plant grows to only about a third of its normal size with leaves that become dark green and curl downward.

In the 1980's, Adrianna D. Hewings and others studying SDV-D, SDV-Y, and subterranean clover red leaf virus confirmed that all three viral strains reacted about the same way in diagnostic tests that employed antibodies.

Antibody tests such as the ELISA (enzyme linked immunosorbent assay) are often used to distinguish the presence of a certain protein in a sample. The test can be tailored to react to and thus detect virtually any protein. In the case of the SDV strains and the clover leaf virus, similar reactions indicated that they were the same virus.

Hewings, an ARS plant pathologist now at the University of Illinois, was the first in this country to purify the SDV-D and SDV-Y strains.

"Based on the test results and other information and the fact that SDV was described in the research literature before subterranean clover red leaf virus, virologists decided to classify the latter as a strain of SDV," says Damsteegt.

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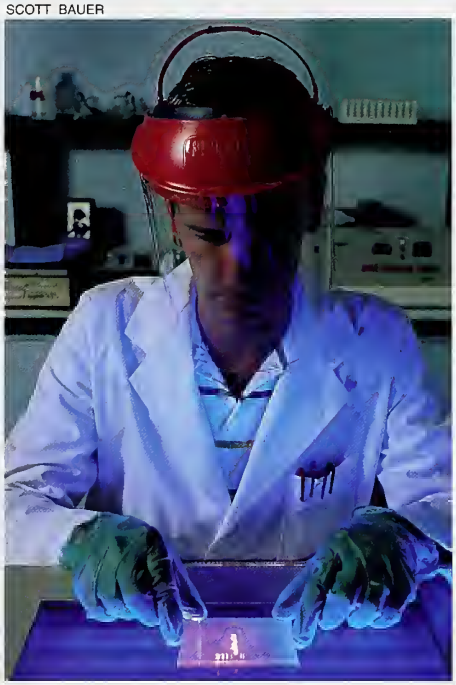

Using ethidium bromide stain and ultraviolet light, plant pathologist Oney Smith detects strain-specific dsRNA of soybean dwarf viruses. (K-4095-11)

Virus Not What Is Expected

In the United States, the virus hasn't been found in soybeans, but it may be wrong to assume that the virus isn't here at all.

In 1983, an SDV-like pathogen was isolated from legumes by James E. Duffus, who works for the ARS Sugarbeet Production Research Laboratory in Salinas, California. This isolate was specifically transmitted by the pea aphid, *Acyrthosiphon pisum*. Then, SDV-like pathogens from white clover were found in the Carolinas, Florida, Kentucky, Maryland, Mississippi, and Virginia.

Very interestingly, all these isolates were transmitted by the pea aphid and produced leaf-reddening when injected into subterranean clover.

Part of Damsteegt's and Smith's job is to determine if SDV is a potential threat to U.S. soybean production. At the Frederick quarantine facility, researchers work with plant pathogens from all over the world.

Now the plant pathologists have found a way to differentiate between the two Japanese strains of SDV. "The method examines the virus' RNA chromosome using double-stranded RNA analysis," says Smith.

How the Virus Works

The virus has a six-sided protein shell that surrounds and protects a single-stranded RNA chromosome, its genetic material. When the aphid feeds, the virus infects the plant and releases this RNA. This forces the plant cells to reproduce the virus' RNA.

"Viruses aren't technically alive because they can't reproduce their own RNA," explains Damsteegt. "They need plants to do it for them."

Once the aphid injects the virus into the plant, the virus releases its RNA chromosome. The single-stranded RNA is converted to double-stranded RNA (dsRNA), as a part of the life cycle of the virus. The scientists can isolate this dsRNA and genetically "fingerprint" it with a standard laboratory technique that uses a small electrical current to separate various nucleic acid molecules into bands within a gel material.

"Using the dsRNA analysis is a very accurate way to differentiate

between the D and Y strains of SDV," says Smith. Each strain produces two size-specific dsRNA's with different molecular weights that stop at particular levels on the gel.

Smith and Damsteegt now want to apply the technique to see what other soybean dwarf virus strains exist in the world.

After Duffus' identification of an SDV-like virus transmitted only by the pea aphid, interest was generated through the Southern Regional Research Project S-228, "Forage Legume Viruses," to search for SDV-like viruses and other luteoviruses in legumes in the United States. The Committee, made up of researchers from the southeastern states, is working to understand and control viruses in forage legumes.

In the past 5 years, scientists at the Frederick lab and Duffus' lab, and Michael R. McLaughlin at the Forage Research Unit, Mississippi State, Mississippi, have identified several SDV-like isolates. What damage they do to legume crops or pastures is being investigated.

So, is SDV exotic? Maybe some strains are, says Damsteegt, but for soybeans, the Japanese biotype (or subspecies) of the foxglove aphid may be more exotic than the virus it transmits.

"Where has the research on SDV taken us?" he adds. "To a better understanding of the occurrence and distribution of a previously poorly understood virus and to the realization that viruses may already occur in areas we believe they do not."—By **Dvora Aksler Konstant,** ARS.

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SCOTT BAUER

Adult pea aphids, about an 1/8th inch long, transmit an SDV-like virus to clover in the United States. (K-4097-6)

A Unique Evolutionary Relationship

Before Vernon Damsteegt could begin to figure out where the soybean dwarf virus was coming from, he first had to determine which aphid was carrying the virus.

All aphids are parthenogenic, meaning they are produced asexually as clones of their mothers. Would they then feed on the same plants? And is there a danger they could spread the virus to U.S. soybeans?

Damsteegt tested green and yellow biotypes (or subspecies) of soybean-feeding foxglove aphids from Japan, and nonsoybean feeders from California, New Zealand, and New Brunswick, Canada. The aphids were identified by Manya Stoetzel, who is with the ARS Systematic Entomology Laboratory in Beltsville, Maryland.

This foxglove aphid feeds on soybeans in Japan, carrying the virus to that crop with devastating results. If only half of the plants in a soybean field become infected with the virus, yield drops by about 40 percent.

The same aphid exists in the United States, but it seems to ignore the soybeans and favors clover and potatoes. "It appears that U.S. aphids just don't like soybeans," says Damsteegt.

The pea aphid, *Acyrthosiphon pisum,* also carries strains of the virus. It feeds on clovers, peas, french and broad beans, lentils, lupines, and sugar beets but doesn't like soybeans.

Damsteegt thinks that each of the aphid biotypes is virus-specific; that is, each carries only one form of the virus.

"Though the soybean dwarf virus is a group of closely related strains, those transmitted by the foxglove aphid are exotic to the United States," he says, "whereas all endemic SDV-like viruses are carried specifically by the pea aphid. So there may not be much danger to U.S. soybeans," he says.

"There is a unique evolutionary relationship, and a very specific one, between the aphids, the viruses, and the plants," says Damsteegt.—**Dvora Aksler Konstant,** ARS.

Fine Dining for the Loathsome Screwworm

Some 5.3 billion government-reared screwworm larvae went on a diet last year. The savings in their $100,000-a-week feed bill amounted to 25 percent.

Besides saving money, the new rearing system helps the Mexican-American Commission for Eradication of Screwworm produce healthier insects that have a better chance to compete for matings in the wild. The larvae are reared to mature pupae, sterilized by radiation, and dispersed as adults to stop reproduction of their own kind in nature.

USDA/APHIS

Screwworm larvae.

By releasing sterile screwworms to mate with the wild population, ARS scientists succeeded in eliminating the screwworm from the United States as long ago as 1966 and more recently in Mexico. Now, thanks to cooperation from Mexican authorities, scientists are working to push their control over this dread parasite ever southward into neighboring Central American countries.

In nature, metallic-blue-green adult female screwworms—about twice the size of the common house fly—lay eggs next to flesh wounds on cattle, sheep, dogs, and other mammals, including humans. When the eggs hatch, the larvae enter the wounds and feed on living tissue.

But in a rearing factory, a diet of living flesh is out of the question. In an effort to simulate the parasites' ghastly natural preferences, scientists have developed other means of sustenance. For years, larvae were supported by acetate fibers as they fed on a liquid diet. Every 4 hours, workers had to vacuum off waste diet loaded with metabolic wastes and refeed with fresh diet.

This labor-intensive system has now been replaced by a gelled diet that incorporates the usual spray-dried bovine blood, spray-dried egg, and milk substitute.

"Larvae thrive on the gelled diet. It enables them to get together to feed, much as they would in nature," says David B. Taylor, an insect geneticist who is now at the ARS Bioscience Research Laboratory, Fargo, North Dakota, where he is looking for a way to genetically separate male from female larvae as a means of cutting costs.

Taylor and colleagues of USDA's Animal and Plant Health Inspection Service (APHIS) and Mexico's Ministry of Agriculture and Water Resources (SARH) conducted the scaled-up pilot tests, rearing 15 million screwworms per week at a factory in Chiapa de Corzo, Chiapas, Mexico.

In the spring of 1990, the entire facility converted to the new rearing method.

Improved efficiency has already offset the renovation cost. With less diet wasted by the new system, there is less disposal. And discarded diet may be processed one day soon into livestock feed supplements or soil conditioners for nearby farms.

Then there's the payoff of more and healthier sterile insects produced from egg to adult. "Within a month after complete conversion to the new system, we had more than 90 percent emergence of adult flies from pupae, as opposed to 85 percent under the former system," said H. Chris Hofmann, plant director.

The factory, which is the world's largest insectary, has recently been producing a quota of about 190 million sterile flies each week. With present floor space, "we could eventually expand operations to produce over 500 million flies per week," says Hofmann.

Factory employees sterilize screwworm flies for air release in Belize and Guatemala and in an area around the production site.

Until ARS entomologists (now retired) Edward F. Knipling and Raymond C. Bushland pioneered the sterile-release strategy in the 1950's, screwworms were the scourge of U.S. livestock.

Since the pest has been eradicated from the United States and Mexico, livestock producers and consumers have saved an estimated $10 billion in the United States and more than $2 billion in Mexico. By continually pushing the frontier of screwworm infestation south, USDA avoids the greater expense of trying to control the pest along the lengthy U.S.-Mexico border.—By **Ben Hardin,** ARS.

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The Great Wheatgrass Bake-Off

DE IRVING

Baked goods made from all-wheatgrass flour and from various blends with wheat flour.

Taste testers have discovered a secret that cows have known for a long time—wheatgrass tastes good.

Food panelists liked the appearance, texture, and flavor of cookies and muffins baked with intermediate wheatgrass flour. They also enjoyed bread made from wheatgrass flour that was blended with conventional wheat flours.

ARS chemist Robert Becker at Albany, California, says the tests are an early indication of how well products made from this relative of bread wheat might fare with choosy consumers in marketplaces of the future.

The grain gets its name from its height—intermediate between two other kinds of wheatgrass.

Intermediate wheatgrass is currently grown for hay, or planted on pastures and ranges grazed by cattle, sheep, or horses. Seed prices range from about fifty cents to $1.25 a pound, depending on demand.

Wildlife also like wheatgrass—rabbits and deer eat the tender green shoots of young plants.

For the Albany experiments, more than 50 taste testers sampled baked goods prepared by food technologist Den-Shun Huang (now at the California Wheat Commission Laboratory in Woodland). He used 15 percent intermediate wheatgrass flour, 80 percent whole wheat flour, and 5 percent wheat gluten to bake breads that resemble whole grain loaves. Wheatgrass gave the breads a distinctive, nutlike taste.

KEITH WELLER

Wheatgrass seeds, smaller and lighter than those of commercial wheats, can be ground into flour or cooked whole, like rice. (K-4082-5)

Huang relied on wheatgrass flour for flavorful muffins, and wheatgrass plus oatmeal for soft chocolate chip/oatmeal cookies. He used 50 percent wheatgrass flour to make banana bread, which had a mildly banana-nut flavor and was moist but not soggy.

Becker, along with Peggy A. Wagoner of the Rodale Institute Research Center, Kutztown, Pennsylvania, and former ARS technician Grace D. Hanners orchestrated the study and related experiments that probed the grain's nutritional value. Those tests showed that wheatgrass kernels have 20 percent protein—about 1-1/2 times more than conventional wheats.

For growers, wheatgrass' lifespan gives it an unbeatable advantage over commercial wheats. Wheatgrass is a perennial, meaning that the original field can produce a new grain crop each year for at least 3 and sometimes

10 or more years without replanting. Commercial wheats, in contrast, are annuals. Like oats and rye, they live only 1 year and so require yearly seeding and tilling.

For marginal sites—such as hilly, erosion-prone land that can't withstand the wear and tear of annual crop production—wheatgrass might be a promising future option as an alternative grain crop.

As a perennial, it would provide year-round cover that protects soils from the erosion of wind and rain. In addition, plant regrowth after grain harvest could supply pasture for grazing animals.

Growers who opt to plant perennials on difficult sites might expect savings in fertilizers, herbicides, pesticides, and fuel, too. Maintaining a stand of perennials requires less of those materials than are needed to raise consecutive stands of annual grains.

Wheatgrass is unlikely to compete directly with today's commercial wheats, however. That's because wheat is the only grain that can be made into a dough that rises and provides light, fluffy baked goods.

There are other reasons why Becker and colleagues don't expect amber waves of wheatgrass for flour to spring up overnight. For one thing, yields must be boosted. Today's top-yielding wheatgrasses produce only about 500 pounds of grain per acre, as opposed to about 2,000 pounds from an acre of commercial wheat.

That's because wheatgrasses have been bred for forage, not for grain, explains ARS geneticist John D. Berdahl. Grain varieties produce seedheads loaded with fat kernels. A prized forage grass, in contrast, yields lots of stems and leaves. Boosting grain yield of wheatgrass might take at least 10 years, Berdahl estimates.

"Higher yields should improve the chances that wheatgrass might someday be a grain crop growers could raise economically," says Becker. "Right now, however, the economics are still borderline."

Besides higher yields, they also need advice—based on solid experience—about how to grow a hardy, productive crop. Peggy Wagoner and her co-workers are tackling that problem in test plots at the Rodale Institute.

They're monitoring hundreds of experimental wheatgrasses, including many from Berdahl at Mandan and others from the ARS Plant Introduction Station at Pullman, Washington.

Markets, and practical pointers for those who buy wheatgrass grain, mill wheatgrass flour, or bake with it, must also be developed. All that can happen, Becker says, if there's enough interest in building a new future for this crop.—By **Marcia Wood,** ARS.

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PEGGY WAGONER

Harvesting wheatgrass from experimental plots at the Rodale Institute Research Center in Pennsylvania.

How Sweet It Isn't

RICHARD NOWITZ

Until his retirement last December, Sheldon Reiser spent two-thirds of his research career studying the effects of sugars and other carbohydrates on human metabolism. But no one who knows him would ever call him the Candy Man. Reiser, who headed carbohydrate research at the Beltsville Human Nutrition Research Center for 17 years, has voiced strong concern over the increasing levels of refined sugars—sucrose (table sugar) and high-fructose corn sweeteners—in the U.S. diet.

Shortly after 1900, Americans got twice as many calories from complex carbohydrates—mostly from starches—as they did from simple sugars. Now, simple sugars have taken the lead—accounting for a little more than half of our carbohydrate calories. Since 1975, the calories we get from sweeteners have increased about 14 percent, says Reiser, mostly because of a dramatic increase in the use of high-fructose corn sweeteners in a host of processed foods.

"I'm definitely concerned that sugar consumption at current levels is increasing risk of heart disease and diabetes in a small but significant percentage of the population," says Reiser.

Some 15 percent of Americans are genetically prone to higher-than-normal levels of fat (triglycerides) circulating in their blood—above 150 milligrams per deciliter, he says.

In 1979, he and colleagues demonstrated that sugar further raises triglycerides in these people. He later found that people with high triglycerides generally also have higher-than-normal levels of insulin. He called

Nutritionist Kay Behall's recipes have yielded more than these tasty loaves of bread made with high-amylose cornstarch instead of wheat flour. They may hold the key to preventing increases in blood insulin. (K-4093-2)

these people "carbohydrate sensitive," which he now says is misleading since the troublesome carbohydrate appears to be fructose.

Fructose constitutes close to half of high-fructose corn sweeteners (see box on page 23). Consumed in its natural form—as part of fruits, for example—fructose intake is comparatively small. Also, the fiber in fruits slows down its absorption, smoothing blood levels. But stripped of fiber's tempering effects by refining processes, fructose becomes a more potent metabolic danger in those who are sensitive. Research since the 1960's has shown fructose to be lipogenic (fat formative) in all people, says Reiser. The liver removes nearly all of the absorbed sugar from the blood and converts it into triglycerides, which are secreted back into the blood.

Risk Factors

High triglyceride levels are increasingly recognized as a risk factor for heart disease, primarily because they usually go hand-in-hand with low levels of the "good" HDL cholesterol. Researchers now contend that people who don't have enough HDL to quickly remove cholesterol from their arteries are at highest risk for heart disease.

In subsequent studies by Reiser's group and others, "sugar at levels and in diets reflecting what is consumed in the United States has usually produced significant increases in blood triglycerides in people with elevated triglycerides, insulin, or both," he says.

In studies where the increases were not significant, the diets contained extra fiber or a higher ratio of polyunsaturated fat to saturated fat than most Americans eat, he notes. These factors seem to counteract the effects of fructose. Also, he adds, fructose doesn't seem to affect younger women as it does men and postmenopausal women. However, it can interact with oral contraceptives, jacking up insulin levels in women taking "the pill."

Fructose significantly increases triglycerides even in men who have normal levels, though it doesn't push them above the normal range. It is estimated that fructose from all dietary sources accounts for about 8 to 10 percent of the calories in U.S. diets. "It would have to exceed 21 percent to

KEITH WELLER

The fiber in complex carbohydrates—grain, fruit, and vegetables—can reduce the body's absorption of fructose, even from fruit which is naturally high in the sugar. (K-3839-3)

produce significant increases in triglycerides in people who are not fructose sensitive," Reiser says. And at that level, fructose also promoted another recognized risk factor for heart disease—elevated levels of uric acid—in both sensitive and normal men, he adds.

More recently, other researchers have reported that people with elevated triglycerides overproduce a chemical component called the superoxide free radical. This molecular pickpocket can damage a variety of cell structures, including DNA, and is thought to promote aging.

A jump in fructose consumption could do more than raise triglycerides. In 1983, Reiser's colleague Judith Hallfrisch, who now heads the Beltsville lab, demonstrated that 5 weeks of consuming fructose—at less than twice the level currently consumed—prompted people with both normal and high insulin levels to secrete more insulin during a glucose tolerance test. Those with high insulin showed the greatest increase, says Reiser. Subsequent studies by others have shown similar results.

"High insulin is believed to be one of the earliest signs of noninsulin-dependent, or type II, diabetes," he says. "Fructose has been suggested as a sugar that can be safely consumed by people with impaired glucose tolerance because the body does not use insulin to metabolize fructose. It's true that when consumed alone, fructose does not significantly increase either insulin or glucose levels in the blood," he says. "But fructose is almost always consumed along with glucose." For instance, sucrose (table sugar) and high-fructose corn sweeteners are about half glucose.

Reiser says studies indicate that fructose somehow reduces the affinity of insulin for its receptor—the first step in getting glucose into a cell and metabolized. As a result, the body pumps out more insulin to handle the same amount of glucose.

Reiser's concern is that triglyceride and insulin levels increase as people age. "Fifteen percent is an average of the total population," he says. "Fewer than 15 percent of young people are fructose sensitive, but more than 15 percent of older people are."

The unanswered question is whether the trait develops only in those with faulty genes or whether years of pandering to the sweet tooth can push others into this danger zone as well.

Reiser says that current recommendations to reduce fat intake by increas-

ing carbohydrates in the diet have the potential to further boost sugar intake. The American Heart Association, the American Dietetic Association, and other groups recommend increasing carbohydrates from the current 47 percent of total calories to between 55 and 60 percent. While these groups have emphasized that we eat more complex carbohydrates—grains, fruits, and vegetables—will consumers practice what is preached? Or will they figure one carbohydrate's as good as another—as long as it's not fat?

Fat Rats

Otho Michaelis, a research biologist in the Carbohydrate Nutrition Laboratory, doesn't think that sugar causes type II diabetes. But he does think "it could contribute to the time of onset and severity of its expression in people with a particular genetic background."

In the early 1980's, Michaelis began searching for a rat model that resembles the 15 percent of the population Reiser found to be sugar sensitive—those who may go on to develop diabetes. He now works with three genetically obese models—all of them developed at the National Institutes of Health to study the complications of obesity. One model develops both high blood pressure and diabetes, another develops diabetes only, and the third is simply very fat.

"These rats are not little people; their characteristics are not identical to what you see in human obesity and diabetes," he says, "but there are similarities." By using strains of rats that exhibit obesity, impared glucose tolerance, and high blood pressure in different combinations, "we get a better picture of the influence of each of these factors on the development of diabetes."

He says the rats genetically prone to diabetes "develop the disease whether or not you feed them sugar. But a high-sugar diet magnifies blood glucose, insulin, and other glucoregulatory hormones as well as triglycerides and cholesterol. And it accelerates the structural damage to kidneys and possibly other organs."

Sugar also affects the model that does not develop diabetes, he notes, increasing the metabolic risk factors to a lesser degree.

The Copper Connection

Another foible of fructose is that it exacerbates copper deficiency—at least in male animals. In study after and much higher in fructose than we usually eat (63 percent of total calories). But a similar study reported by Daniel J. Scholfield and colleagues on pigs brings the findings closer to home. At 20 percent of total calories, the fructose content of the pigs' diet was only twice the level in the average U.S. diet, which is generally low in copper. Yet the copper-deficient, fructose-fed pigs also developed a more pronounced anemia, liver damage, and severely enlarged hearts. And pigs have cardiovascular and digestive systems very similar to humans, notes Scholfield.

SCOTT BAUER

Former head of carbohydrate nutrition studies, Sheldon Reiser (right) chats with study volunteers Laura Kressler and George Marechek during breakfast. Meanwhile, research cook Sue Burns (background) readies another precisely weighed meal. (K-4109-8)

study, young male rats developed severe anemia and enlarged hearts and livers and died prematurely from copper-deficient diets only when the main source of carbohydrate was sugar, says colleague Meira Fields. "When it was starch, nothing happened."

The animals' diets may be far more deficient in copper than people's diets

Fields says fructose and substances that are metabolized similarly, such as alcohol, "create a unique environment in which copper deficiency can cause damage." Starch, on the other hand, "isn't involved in the damaging pathway," she says. Starch is composed of long chains of

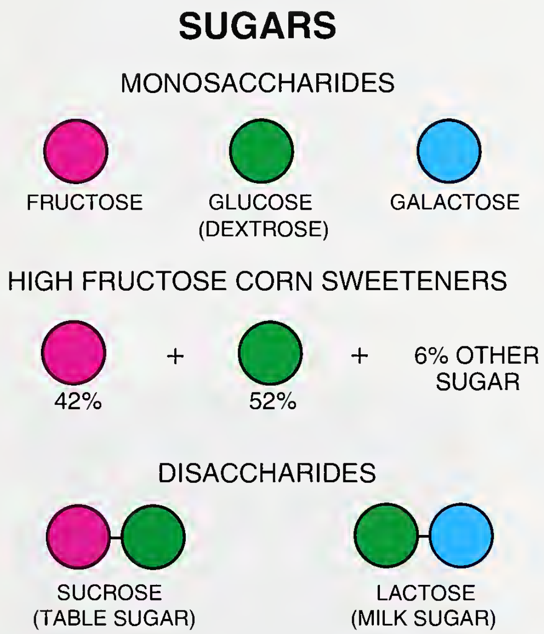
glucose units and contains no fructose.

Fields and colleagues recently found that damage to the heart and other organs hinges on a change in the way the animals handle another mineral—iron. Although all copper-deficient rats accumulate iron in their livers, those getting high levels of fructose can't use what they have—resulting in anemia, she explains. And much of the stored iron appears to be in the form that generates free radicals, which explains the organ damage.

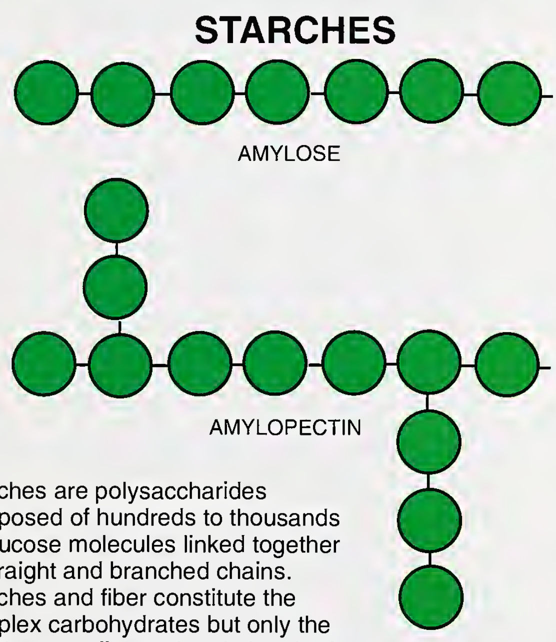
Her studies have also shown that alcohol leads to the same kind of tissue damage in copper-deficient rats that fructose causes. Adding 20 percent alcohol to the animals' drinking water produced heart muscle damage, anemia, fatty liver, and elevated levels of several toxic metabolites.

"These are all classic effects of human alcoholism," she says. If the animals got adequate copper in their feed, however, they didn't suffer these consequences, leading Fields to speculate that the human alcoholic syndrome may be a result of too little copper in combination with too much alcohol.

Rats and people process fructose and alcohol using similar metabolic pathways, she explains, but they use different pathways to process the



Nutritionally important sugars come in two sizes—a single molecule, or monosaccharide, and a pair of monosaccharides called a disaccharide. Since the body absorbs only single molecules of sugar, it uses the digestive enzymes sucrase and lactase to break the connecting bond in disaccharides. High-fructose corn sweeteners are commonly less than half fructose.



Starches are polysaccharides composed of hundreds to thousands of glucose molecules linked together in straight and branched chains. Starches and fiber constitute the complex carbohydrates but only the starches are digested and absorbed, providing calories to the body.

glucose from starch. "If our hypothesis is correct, and a certain metabolic pathway interacts with copper deficiency, then any nutrient that mimics fructose metabolism should produce the same damage."

There's Starch and Then There's Starch

Not all the news coming out of the Carbohydrate Nutrition Laboratory is bad. The good news is that a particular form of starch—amylose—has the opposite effect of fructose on risk factors for heart disease and diabetes in both normal and fructose-sensitive people. The problem is that plant foods have a lot more of the other form of starch—amylopectin.

About the time Reiser identified fructose sensitivity, researchers elsewhere were noting that people responded to starch from different plant foods with greater or lesser rises in blood glucose and insulin levels. It looked as though the form of starch might be a factor because legumes—with 30 to 40 percent amylose—produced lower responses in glucose tolerance tests than potatoes and cereal grains—with only 20 to 28 percent amylose.

To confirm that amylose and not fiber or some mineral was caus-

ing the beneficial effect, Kay Behall at the Beltsville lab began testing purified starches on people. She found a cornstarch, developed more than 30 years ago to make gelled candies set faster, that contained 70 percent amylose compared with the 25 to 30 percent in standard cornstarches.

Behall and coworkers have compared the effects of crackers, brownies, muffins, and other foods made with both starches in acute response tests.

"We see a significant drop in blood insulin levels with high-amylose foods compared to high-amylopectin," says Behall. "High-amylose foods did not significantly reduce glucose levels over the course of the 3-hour test. But they did keep the levels from peaking and then bottoming out as occurred with high-amylopectin."

Moreover, in a 10-week study, she says, eating high-amylose foods for 5 weeks significantly lowered triglyceride and cholesterol levels in the subjects as compared with 5 weeks of eating high-amylopectin foods.

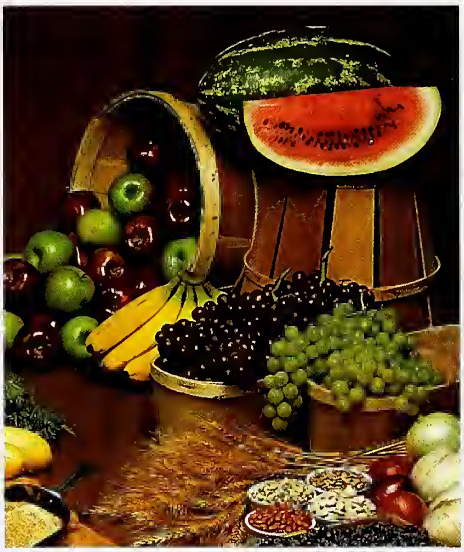
Recently, 24 dedicated men—about half of them with high insulin—finished a 28-week study comparing the 2 starches. For the first 10 weeks out of each 14-week period, nearly all of their starchy foods were prepared by Behall and company. The other 4 weeks they ate nothing but "home-cooked" meals (which included the special starch foods) from Beltsville's diet kitchen.

George Marechek—a veteran volunteer of center studies—found the diet easy to stick with, noting that "family support is very important because you could have only one outside starch." Compatriot Owen Kardatzke had a little more difficulty with the rigors of research eating, especially during the Christmas season. "You'd be surprised how many things at parties contain starch—cookies, little sandwiches, potato chips," he notes.

When all the data is analyzed, the study should provide solid evidence of the long-term effects of increasing amylose in our diets. The men got about 20 percent of their calories from high-amylose or high-amylopectin starch, which is close to the U.S. average for starch calories—about 22 percent.

"We don't know whether starch with a lower amylose content or meals

KEITH WELLER



with a lower percentage will also be effective," Behall says. That's the question for another study.

Behall says the beneficial effects of high-amylose foods appear to be due to slower digestion and absorption of glucose. Amylose is a straight chain of glucose units, whereas amylopectin is a highly branched chain, she explains (see box). Since the digestive enzyme lops off glucose units only from the free ends, amylose releases far fewer units in a given period of time than amylopectin.

The difference in structure also means amylose requires different cooking methods since it does not have the same gelling properties as amylopectin. Behall and her coworkers have had to work around this problem to produce recipes that are palatable.

Kardatzke and Marechek noticed a difference between the two starches as did most of the men. "There was a big difference in some of the products," Kardatzke says. But the bran muffins and cookies tasted about the same to him—"after they made the cookies more crisp and crunchy," he adds. "At first, they were more like lumps of play-dough. It would rub off on your fingers as you ate them."

Marechek noticed a difference in the texture of cheese puffs and cereal. "The high-amylose cereal was more difficult to chew—coarser and heavier," he says. "I would sprinkle raisins on it to make it more like raisin bran than cornflakes," he says.

Behall said all the men generally favored the high-amylopectin products, except for the muffins. But, she adds, "Remember, these are research products. I could get a cookie that sticks together better or moister bread, for instance, if I could add gum. But the gum would augment the effects of amylose and confound the research," she notes.

"If we can show that high amylose is good nutritionally," says Behall, "I'm sure that there will be some commercial interest in producing specialty foods.

But before high-amylose products become commonplace in the U.S. diet, plant breeders or genetic engineers will have to increase the percentage of amylose in wheat—the staff of life.—By **Judy McBride**, ARS.

Kay Behall, Meira Fields, Otho Michaelis, and Daniel Scholfield are with the USDA-ARS Carbohydrate Nutrition Laboratory, Beltsville Human Nutrition Resarch Center, Bldg. 307, BARC-East, 10300 Baltimore Ave., Beltsville, MD 20705-2350. Phone (301) 344-5412. ◆

Update for an Ancient Watering Strategy

Water harvesting is simply capturing and storing precipitation that would have seeped into soil or run off into stream channels. One creates a sloping surface that's impervious to water and fashions dams at the bottom to funnel precipitation onto crops or into storage containers.

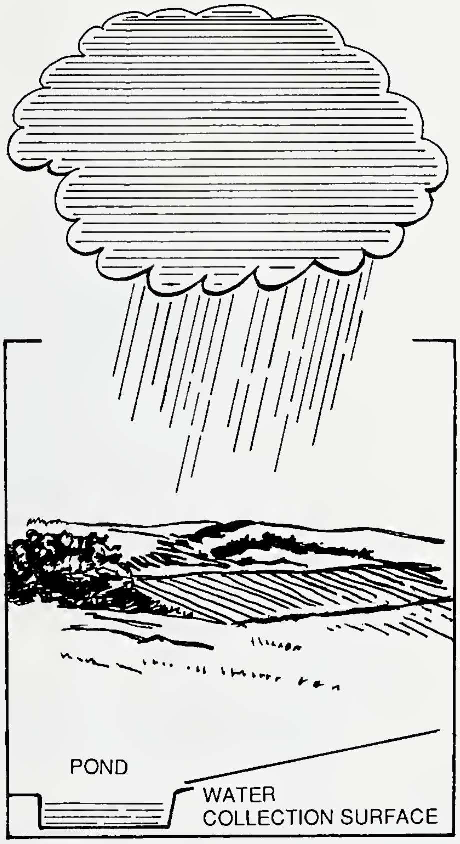
The world's first harvesting system for drinking water was probably near the Ur areas in present day Iraq. Archaeological investigations in that region suggest water was collected as long ago as 4500 BC. Traces of those systems, which once supplied water for caravans and pilgrimages, can still be seen today along desert roads from the Arabian Gulf to Mecca.

During the past 6,500 years, many water harvesting designs have been tried and abandoned, but only relatively recently have scientists been called on to help ensure their success.

"There are many separate elements that must be considered, including precipitation patterns, land topography, cost of alternative water sources, and availability of materials, equipment, and labor," says Gary W. Frasier. Many of the factors are interrelated and must be considered simultaneously. Depending on the site and locally available materials, the collection surface can be waterproofed by compacted dirt (like those first ones), melted wax, asphalt, concrete, or plastic films.

Frasier, a hydraulic engineer with the Agricultural Research Service, has designed, modified, refined, tested, and evaluated hundreds of water harvesting systems during the past 30 years.

Recently he evaluated some of the water harvesting systems he helped build on the Fort Apache Indian



Reservation in central Arizona. He cooperated with Sherri L. Simper, a range conservationist with the U.S. Department of the Interior's Bureau of Indian Affairs. Two of the original systems built there more than 25 years ago are still supplying drinking water to livestock.

One system is a combination of fiberglass matting and asphalt and the other a cover of chlorinated polyethylene sheets glued together.

With the fiberglass and asphalt, the matting is spread out on a smoothed area and saturated with a water-based asphalt. The asphalt soaks through the fiberglass and bonds the fabric to the underlying soil. This forms a waterproof, semirigid membrane that stands up to small animals that wander across it. Fences keep larger animals off.

Minor fence maintenance, plant removal, and re-coats of asphalt at 3-to 5-year intervals have been the only remedial measures necessary to extend its life beyond original design expectations. This treatment is still being used on other sites in various places in the United States. The USDA's Forest Service and Department of the Interior's Bureau of Land Management are two major users.

"Unfortunately, the polyethylene sheeting used on the other catchment is no longer manufactured. A different type of sheeting may be on the market, but we don't yet know if it will survive the ravages of wind and sun," says Frasier.

With flexible sheet covering, the key is finding a material that has chemical and physical characteristics that allow the cemented-together sheets to conform to all surface irregularities and withstand winds.

Frasier has authored a comprehensive how-to book on the subject and continues to receive inquiries from potential users.

Most recently, Texas ranchers have solicited his help to provide water for deer and other wildlife. Farmers and ranchers often supplement their incomes by charging hunters for using their land. Fees they collect are based on amount of wildlife their lands support.—By **Dennis Senft,** ARS.

Gary W. Frasier is at the USDA-ARS Rangeland Resource Research Unit, Crops Research Laboratory, 1701 Center Ave., Fort Collins, CO 80526. Phone (303) 484-8777. ◆

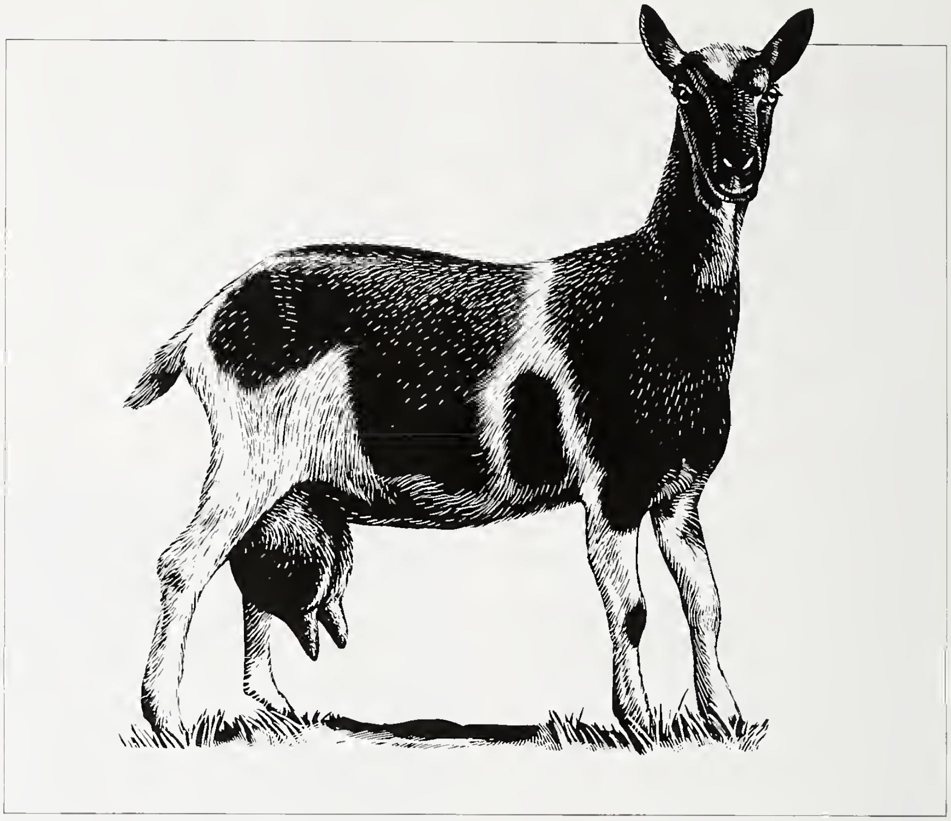
Dances With Goats

Sam Coleman has learned a thing or two about goats in the last few years.

For one thing, Coleman says, goats may well be the animal kingdom's version of a perpetual motion machine.

"They're like cattle—they don't really sleep, they just rest," says Coleman, an animal scientist with the Agricultural Research Service's Forage and Livestock Research Unit at El Reno, Oklahoma.

Coleman has observed firsthand how an average goat spends its day. He's cooperated with Christopher D. Lu of the Kika de la Garza Institute for Goat Research, located at Langston University in Langston, Oklahoma, on two studies aimed at helping small farmers get the most from their goat herds.



One study, done in 1988-89, looked at the link between the amount of fiber in a goat's diet and how much forage that goat could gobble—and turn into meat—in a day's time.

Each of 20 goats was fed a different hay, from poor-quality bermudagrass with 40 percent digestibility to alfalfa hay with 68 percent digestibility.

Each goat ate its selected hay for a 2-week adjustment period, then for another 5 days as scientists collected the animals' feces and urine. The scientists also recorded the goats' activities every 5 minutes for a 24-hour period.

The trials were repeated three times, each time switching each goat to a different forage, but reducing the adjustment period to a week.

"The overall result was, the higher the fiber, the less the goats ate," Coleman reports.

On alfalfa hay, which contained about 29 percent fiber (as determined by the acid detergent method), the goats consumed about 811 grams a day, Coleman reports. But on a grass hay with 44 percent fiber, for example, the goats ate only 551 grams (1.2 pounds) per day.

"The difference is that they spent almost 50 percent more of their time chewing the grass hay than the alfalfa," Coleman notes. "It takes so long to break down the particles and move them out of their system that they simply can't eat as much."

This could be important news for the farmer trying to boost average daily weight gains.

"All goat producers, with the possible exception of dairy goat producers, will just feed hay or what's on the ground," Coleman says. "So the sort of diets we were using in our tests would be fairly typical."

But high fiber isn't always bad news, depending on the farmer's purpose. In a companion study done at Langston University in 1989, Coleman and Lu found that higher fiber can result in higher milk fat content.

In that study, 40 Alpine dairy goats ate diets with fiber levels of either 14, 18, 22, or 26 percent.

Goats' milk typically contains 4.5 to 5 percent milk fat. Milk from 10 goats on the 14 percent fiber experimental diet averaged 5.3 percent 2 weeks after the goats had given birth, and the level climbed even higher, to 5.8 percent, for the goats receiving 26 percent acid detergent fiber in their diet.

"The fiber content of any of these diets is probably okay," says Coleman. "But if a dairy goat producer is really striving for milk fat production, my recommendation would be to go to a higher fiber diet."

Coleman's work with Langston University was part of a program instituted by ARS in the mid-1980's to promote cooperative studies with historically black land-grant colleges and universities.

The Morrill Act of 1862 provided for the establishment of at least one land-grant institution in each state. Under the subsequent Morrill Act of 1890, support was provided for land-grant schools for blacks. Eighteen land-grant schools designated as 1890 institutions are located in Missouri, Mississippi, Arkansas, South Carolina, Alabama, Texas, Louisiana, Virginia, Kentucky, Maryland, Florida, Delaware, North Carolina, West Virginia, Georgia, Oklahoma, and Tennessee.

Steven P. Hart, another animal scientist at ARS' El Reno facility, has also cooperated—with Tilahun Sahlu of Langston University—on goat research under the 1890 program.

Hart's study uncovered an oddity of Angora goats: In good times or bad, the Angora is genetically geared to grow hair, even at the expense of the goat's body.

Hart put one group of Nubian meat goats, Alpine dairy goats, and Angora hair goats on a wheat-pasture diet offering 18 percent crude protein and a matching mixture of goats on low-quality dormant bermudagrass offering only 5 percent crude protein.

At the end of 10 weeks, all breeds on the high-quality diet had gained about the same amount of weight: 45 grams per day for the Nubians and Alpines, and 60 grams per day for the Angoras, although 10 grams of the Angoras' daily gain was in hair.

On the low-quality diet, however, the Angoras actually lost 8 grams of body weight per day compared with gains of 24 grams for the Alpines and 19 grams for the Nubians.

"When nutrition isn't adequate, most animals will cease other functions except life," Hart says. "They won't give milk or reproduce, for example. But the Angoras will produce hair, no matter what.

"Because of this unique characteristic, Angoras require higher quality forage if they are to thrive. I think people have the image that goats can survive on trash. Maybe other goats can, but Angoras can't."—By **Sandy Miller Hays,** ARS.

Samuel W. Coleman and Steven P. Hart are in USDA-ARS Forage and Livestock Research, P.O. Box 1199, El Reno, OK 73036. Phone (405) 262-5291. ◆

A Step Forward for Embryo Culture

Sheep and cattle embryos can be kept alive and growing outside the mother's womb for up to 6 days by using tissue-cultured oviduct cells for nourishment.

The technique, called embryo co-culture, was originally developed by ARS scientists for sheep. "This allows us to make sure that only embryos that survive the manipulations of genetic engineering will be implanted into surrogate mothers," says animal physiologist Caird E. Rexroad, Jr., of Beltsville, Maryland.

In practice, single-celled embryos that have had a gene inserted are placed in cultures of cells from a sheep's oviduct. Scientists speculate that certain nutrients from the cultured cells keep the embryos alive and developing.

"So far, we've had a 30-percent success rate of implanting embryos that have been cultured for 3 days in surrogate ewes.

"Embryos cultured for 6 days that are in the blastocyst or hollow ball stage of development—the best phase for implantation—have a 20-percent chance of surviving. We work exclusively with sheep, but other laboratories have had similar results with cattle embryos," says Rexroad.

"Microscopic examination of the cultured embryos reveal whether they are developing properly. For example, an embryo cultured for 3 days should have more than eight cells; any fewer shows development is not proceeding normally," says biologist Anne M. Powell, a colleague of Rexroad on the research.

"Other, more sophisticated techniques can be used in conjunction with co-culture techniques to see if the genes implanted into the embryo have been incorporated into its genetic material," says Powell.

Alternative methods, such as placing gene-implanted cattle embryos in rabbits for 5 days and then removing them for implantation, have a greater chance of success but lack the advantage of the embryos' progress being visible. Culturing embryos in rabbits also requires more labor, and the animals must be destroyed to recover the embryos.

"Co-culture of cattle embryos is not yet ready to replace short-term transfer of genetically manipulated embryos into rabbit oviducts. But its perfection would be a boon to genetic engineers," says Rexroad.—By **Vince Mazzola,** ARS.

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Corrections:
The drawing of ragweed on page 6 of the May 1991 issue is *Ambrosia trifida* not *A. artemisiifolia*. On page 7, the weed labeled wild oats is Japanese brome *(Bromus japonicus),* introduced from Eurasia and now a pest in most of the United States.

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